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OAR RESEARCH REVIEW

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Volume VIII Number 1 January-February 1969

OFFICE OF AEROSPACE RESEARCH

OAR RESEARCH REVIEW

VOLUME VIII NUMBER 1 Jan-Feb 1969

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ON THE COVER:

AFCRL's 84-foot radio telescope has completed its 10th year of operation at the Radio Astronomy Observatory in Hamilton, Mass. During its 10-year history, it has scored a number of firsts. These have included the first transatlantic moon-bounce communications in which it received signals transmitted from the 250-foot Jodrell Bank antenna in England. The AFCRL radio telescope was also one of the first to observe OH radicals in deep space. Astronomers are now studying those radicals for clues to the origin of the universe.

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OARRP 80-1

OAR RESEARCH REVIEW is published bimonthly by the Office of Scientific and Technical Information (RRYC), Hq Office of Aerospace Research, USAF, 1400 Wilson Boulevard, Arlington, Va. 22209. The objective of this publication is to make a positive contribution to the exchange of information concerning Air Force conducted and sponsored research activities.

JACOB SEIDEN *Editor*

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To our Readers:

With this issue, the OAR Research Review has become a bimonthly, rather than a monthly, publication. This change was necessitated by the need to lighten the work load of OAR's Publications Division, Office of Scientific and Technical Information, which has only a small staff, and has a number of other publications for which it is responsible. It is hoped, at the same time, that this shift in schedule will permit our staff to further enhance the quality of the Review.

We would welcome any comments on the above.

The Editor

nucleation phenomena in glass-ceramic materials

DR. G. F. NEILSON
Owens-Illinois Technical Center
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Glass-ceramic materials are highly polycrystalline yet dense solids produced from homogeneous glasses by controlled crystallization. The crystallization process is brought about by a multistage high-temperature heat treatment of the formed product which brings about nucleation and crystal growth of various crystal types, depending upon the initial glass composition and the nature of the heat-treatment process. Since the type of crystal species as well as their number density and size can be controlled in this manner, it is also possible to vary the physical, chemical, and mechanical characteristics of glass-ceramic materials to yield products having a desirable property or combination of properties.

A family of such versatile crystallized glasses has been developed by Owens-Illinois through a steady and sizable research effort by many scientists and technical personnel at its Technical Center over the past years. This research has included the studies of the properties and structure of crystal species, nucleation and growth kinetics, phase-transformation phenomena, chemical composition, amorphous-phase separation, theoretical interpretation of morphology and microstructure, as well as the development of practical techniques for controlling processing variables. Because the properties of these materials can be tailored for a wide variety of applications, various types are now under development for use in the scientific, aerospace, automotive, home-appliance, and chemical processing industries.

The expansivity of a new low-expansion material over a rather wide temperature range is plotted in Figure 1. For comparison, the expansivity of fused silica, which has long been taken as a standard for low-expansion materials, is also shown in this figure. The very low-expansion property that makes this new material unique also gives it great thermal shock resistance. It also has good polishability and chemical durability in comparison to conventional glasses. Astronomers have shown considerable interest in this low-expansion material for optical mirrors for telescopes because of its excellent thermal stability. Mirror blanks for astronomical use are presently being manufactured from it, including 3 approximately 150-inch blanks. It is interesting to note that, although this low-expansion material is largely crystalline, the sizes of the individual crystallites are made sufficiently small such that the finished product is highly transparent.

From the various research programs mentioned previously, considerable insight is being gained as to how to modify, in a controlled manner, the structures of the various crystalline species that can be formed within model crystallizable glasses, and the effects of these structural modifications on the properties of the finished material. The effect of controlled variations of microstructure and crystallite sizes on physical properties is also of considerable interest.

Research efforts, as part of this over-all program, are directed toward a better understanding of the nucleation processes involved in the formation of the glass-ceramic materials. These include obtaining information concerning the mechanisms by which the various phases form and grow, as well as an effort to determine the role played by nucleating agents in initiating and promoting internal crystallization of the major phases. Another aspect of this work is a study of glasses that are undergoing phase separation by means of a mechanism called spinodal decomposition,* a process whereby composition fluctuations spontaneously grow in amplitude but not in spatial extent during a heat treatment. This process may be contrasted to the more familiar homogeneous nucleation and growth mechanism by which nuclei of a critical size and of composition approaching one

** Spinodal decomposition is a spontaneous separation of concentration regions, which leads to the eventual disproportionation of the solution into two phases. However, in contrast to the process of nucleation, during spinodal decomposition there is no defined surface or boundary between differing concentration regions, and there is no energy barrier for phase separation.*

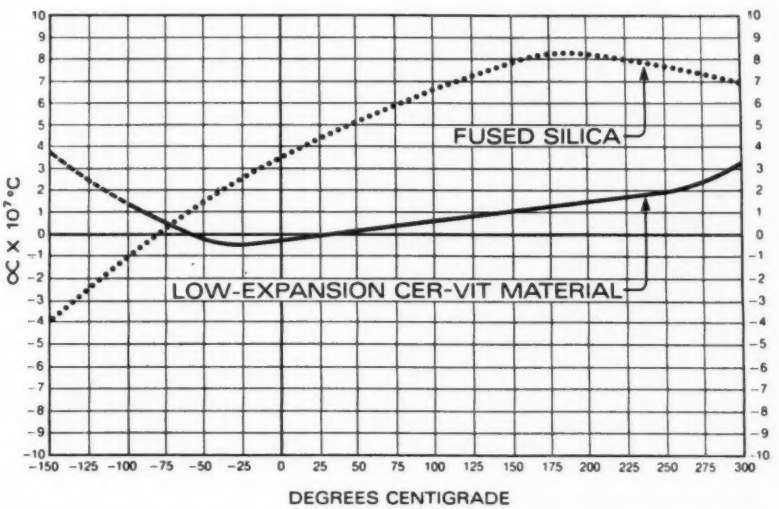

Figure 1. Thermal-expansion coefficient versus temperature curves for low-expansion CER-VIT® material and for fused silica. CER-VIT® is Owens-Illinois' trademark for its line of glass-ceramic materials.

of the two equilibrium phases slowly form and thereafter rapidly grow in spatial extent. A study of spinodal decomposition in glasses becomes important in this program, as this process may be involved in the nucleation and crystallization mechanisms by which certain glass-ceramic materials are formed.

Among the techniques that can be employed to follow nucleation processes in glasses and to obtain information regarding the objectives stated above, small-angle X-ray scattering (SAXS) and electron microscopy appeared to be the most promising and were the primary tools developed and used for this purpose in the present program. SAXS arises from local variations in electron density on a scale of from less than 10 to thousands of angstroms in a material being irradiated. SAXS data can give information concerning the size or size distribution of dispersed heterogeneities. If these heterogeneities are nearly identical in size and shape and are rather widely separated, it is also possible to determine from the scattering data either their concentration or their difference in electron density from that of the matrix, if the other quantity can be independently determined. For a more general case, a system consisting of only 2 phases intermixed in a quite arbitrary manner, it is possible under favorable conditions to determine from SAXS data 2 of the 3 quantities–electron density difference between phases, relative volume fraction of the phases, and total surface area between phases–if the third quantity can be independently determined. An advantage of this technique is that for any material, regardless of complexity, it is possible to determine values for at least 2 parameters that represent macroscopic averages of the extent and degree of heterogeneity. Unfortunately, however, a given scattering curve is usually not unique to one particular distribution of matter, in contrast to diffraction by a crystal. Therefore, SAXS curves can usually be quantitatively interpreted in terms of well-defined physically significant parameters only if a realistic yet sufficiently simple model of the system can be devised. Accordingly, the results obtained and conclusions reached from a SAXS study of a material are most meaningful if an electron-microscopical study of the material can be made in conjunction with the small-angle X-ray scattering study.

Since SAXS has not been widely employed to follow phase separation processes in glasses, an early preliminary objective of this program was to determine the applicability and sensitivity of the method for following the formation of nuclei and the subsequent growth of this new phase in phase-separable glasses. The results were encouraging and showed that this technique can often detect a new phase in an early stage of formation, provided that suitable experimental and instrumental procedures are followed. This work also demonstrated that additional information for characterizing the nucleation processes in glass-ceramic materials can, indeed, be obtained by the SAXS method.

Because commercial materials of this type are multicomponent, it was decided to concentrate on "simple" prototype systems. Accordingly, most investigations to date have been made with a glass of compositions

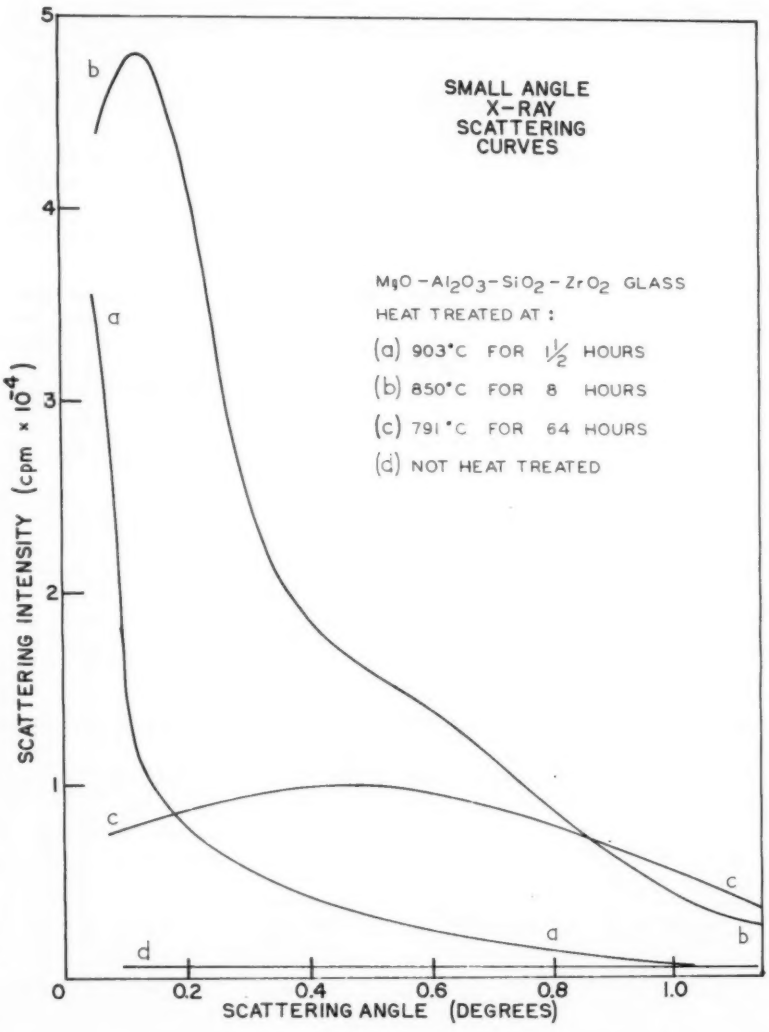

Figure 2. Experimental scattering behavior exhibited by a glass which has undergone incomplete phase separation after heat treating at the three temperatures indicated. The regions containing ZrO_2 which cause the scattering have different characteristics in each case.

$MgO:Al_2O_3:3SiO_2$ plus 10 weight percent of ZrO_2. (1) It has been found that many of the experimental problems associated with a study of this type stem from using glasses which are not sufficiently homogeneous initially on either a microscopic or macroscopic scale; but it was possible to make this particular glass sufficiently homogeneous to satisfy requirements. This system is particularly suitable for SAXS studies because variations in scattering behavior can be interpreted as arising mainly from changes in the distribution of the zirconium ion density. From the scattering and diffraction results obtained, it must be concluded that a phase or phases containing ZrO_2 first develop during heat treatment of this material. Upon further heat treatment, bulk crystallization occurs with the formation and growth of one or more crystalline species containing SiO_2, depending upon the heat-treatment temperature.

Experimentally, slabs of this glass are heat treated for a series of times at a given temperature, quenched to room temperature, and their scattering curves measured. The data obtained through analysis of these curves then give direct information pertaining to the nucleation and growth kinetics, as well as indirect evidence regarding the mechanisms involved. As an example of the type of scattering behavior exhibited, Figure 2 shows the scattering curves obtained when specimens of this glass were heat treated at 791° C, 850° C, and 903° C for the times indicated.

It may be deduced from these curves that the nature of the scattering centers which have developed must be different at each temperature. Through a more detailed study supplemented by electron microscopy and X-ray diffraction of these separated glasses, it can be demonstrated that amorphous separation of a phase that initially becomes gradually enriched in ZrO_2 occurs at the lower temperatures, followed by crystallization of ZrO_2 within these enriched regions when the zirconium-ion concentration becomes critical. However, at high temperatures, the scattering data indicate that ZrO_2 crystallites form by a direct and continuous mechanism without preliminary processes. These results suggest that the mechanism by which these crystallites separate is not related to the mechanism which promotes secondary crystallization. Maxima in scattering curves such as those seen in two of the curves of Figure 2 can be caused by interparticle interference, diffusion depletion zones about independent particles, or periodicity of composition fluctuations such as would be present if spinodal decomposition had occurred. It is often extremely difficult to distinguish experimentally between these effects, and the interpretation of such maxima must accordingly be made with great caution. However, it is highly probable that the maxima in the curves of Figure 2 arise from regions depleted in zirconium ions around each of the particles enriched in ZrO_2, since this model allows quantitative interpretation of all features of these curves in agreement with the microscopic data. This model suggests that the process is diffusion-controlled, which is also in agreement with the growth kinetics observed.

These experiments, however, indicate that the SAXS method can be very useful for studying the complex processes which occur during the formation of glass-ceramic materials. It would appear to be promising to extend studies of this nature to other systems of the glass-ceramic type, and such plans are in progress. Moreover, the SAXS method is also useful for studying amorphous phase separation in the simpler binary glasses in which the nucleation and separation processes would be expected to be less

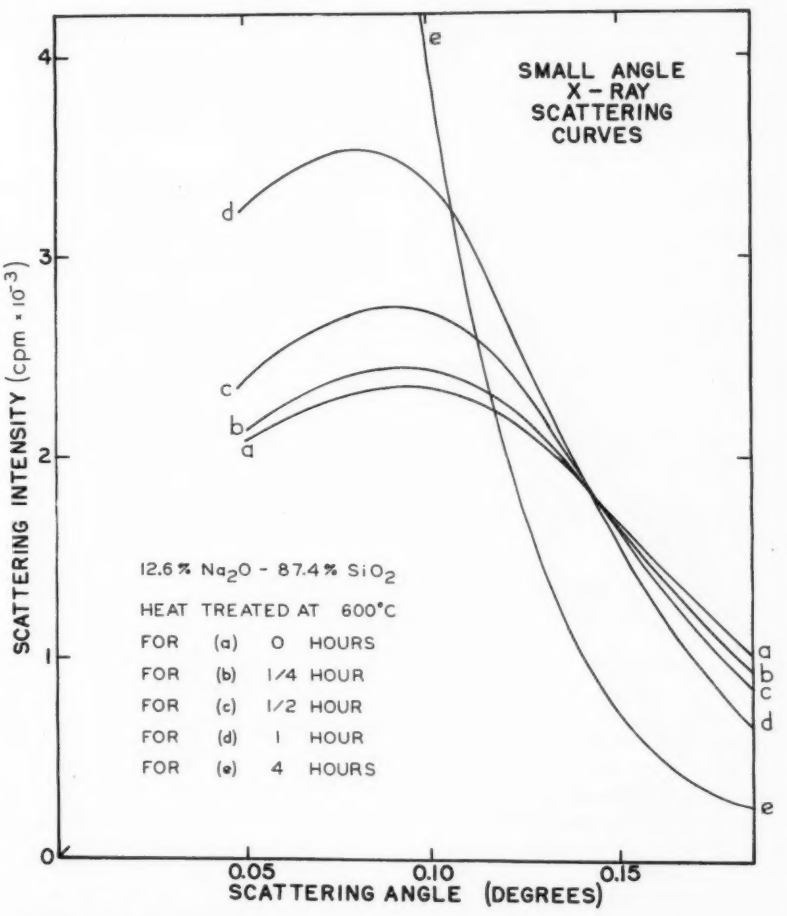

Figure 3. Experimental scattering behavior exhibited by Na_2O-SiO_2 glass after progressive stages of phase separation. The critical scattering angle observed at 0.14 degree is indicative of spinodal decomposition.

complex. It would be hoped that a more thorough understanding of the nucleation processes that can occur in simple glasses could also contribute towards an understanding of similar processes that occur in the more complex systems. Accordingly, the kinetics of phase separation by the SAXS method on a series of compositions in the Na_2O-SiO_2 system is being studied. (2)

In Na_2O-SiO_2 glasses in which the Na_2O concentration is less than about 20 mole percent, metastable amorphous immiscibility has been observed. Glasses of various composition may be prepared in which there is pronounced evidence of interconnectivity and regularity of phases in the decomposed material, which has been cited as evidence that the separation process may have been initiated by means of spinodal decomposition. Small-angle X-ray scattering is an ideal tool for studying spinodal decomposition since, for this particular mechanism, SAXS measurements yield directly the parameters pertaining to the decomposition kinetics. The major experimental problem in this work has been found to be the difficulty in preparing glasses which are sufficiently homogeneous initially. Now this difficulty has been largely overcome, and the results obtained appear very interesting.

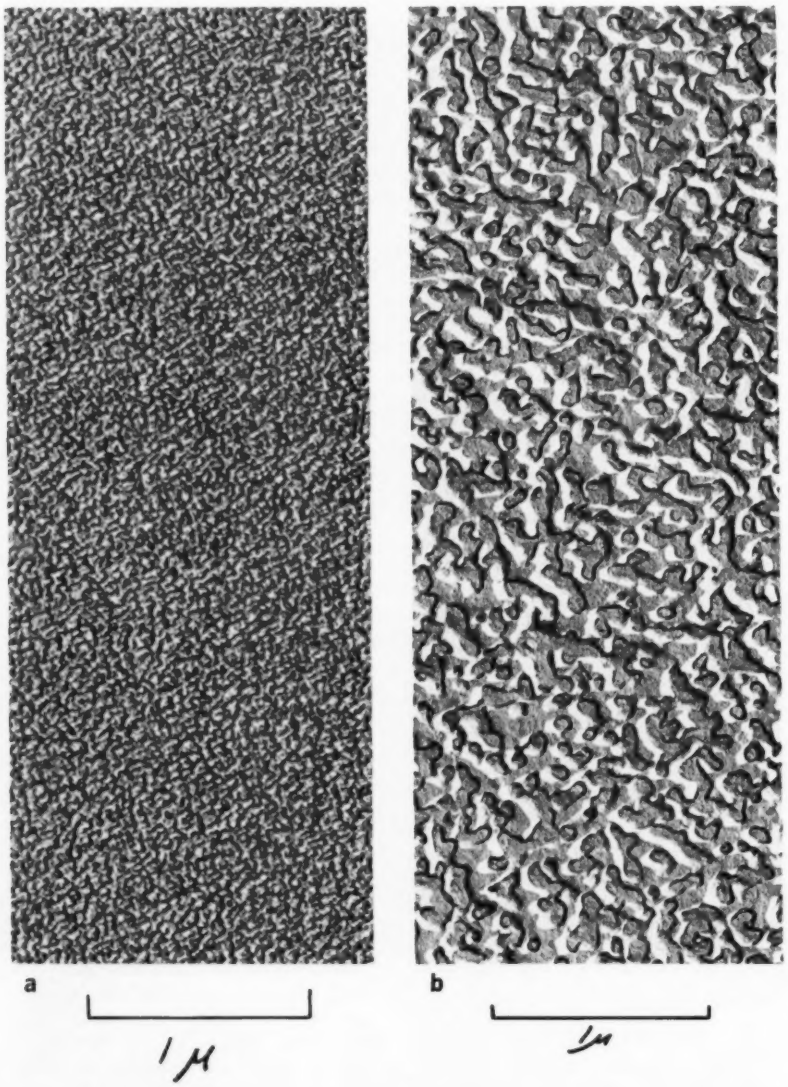

Figure 4. (a) Electron micrograph of Na_2O-SiO_2 glass before heat treatment. (b) Electron micrograph of Na_2O-SiO_2 glass after heat treatment in spinodal region (600° C for 4 hours). The morphology is indicative of that associated with an initial separation via a spinodal mechanism.

The two micrographs were made by replica technique. The platinum-carbon replicas were taken from fracture surfaces of the samples.

These are positive micrographs. The very dark areas represent areas of high relief where the platinum deposition accumulated during shadowing. The white areas represent areas where little platinum accumulated and thus are shaded areas. The position of the shaded areas with respect to the very dark areas allows one to distinguish between areas of low and high relief (hills versus valleys).

In Figure 3 are shown the scattering curves obtained when a glass containing 12.6 mole percent Na_2O is heated at 600° C for the times indicated, and then quenched. For this composition-temperature relation, the electron micrographs of the decomposed material indicate that the glass is in the unstable or spinodal region (Figure 4).

The solution of the differential equation describing the kinetics of spinodal decomposition for early times yields the Fourier transform of the time-dependent composition variation, which may be identified with the angular X-ray intensity distribution scattered at small angles. This equation predicts that, during the initial decomposition, the components of large wavelength (low scattering angle) will grow, whereas those components of sufficiently small wavelength (high scattering angle) will spontaneously decay. Also predicted is a critical scattering angle at which the intensity does not change as the process proceeds. Thus, the appearance of such a critical scattering angle in Figure 3 is considered as strong evidence that the separation at early times is actually proceeding by a spinodal mechanism. The temperature dependence of this critical angle has also been found to be in agreement with spinodal theory. At later stages of the separation process, a critical angle is not required by theory; rather, at some time, the scattering will begin to continuously shift to decreasing angle as observed (see curve

of 4-hour heat treatment in Figure 3).

However, in order to obtain quantitative agreement for the angular dependence of the rate of change of intensity, it appears necessary to postulate that the initial separation process is more complex than would be predicted by simple spinodal theory. The type of information obtained through this work should eventually permit one to distinguish between classical nucleation processes and spinodal mechanisms in more complex systems, and provide a greater insight into the nature of the diffusion mechanisms involved in phase-separation processes in glass-ceramic materials.

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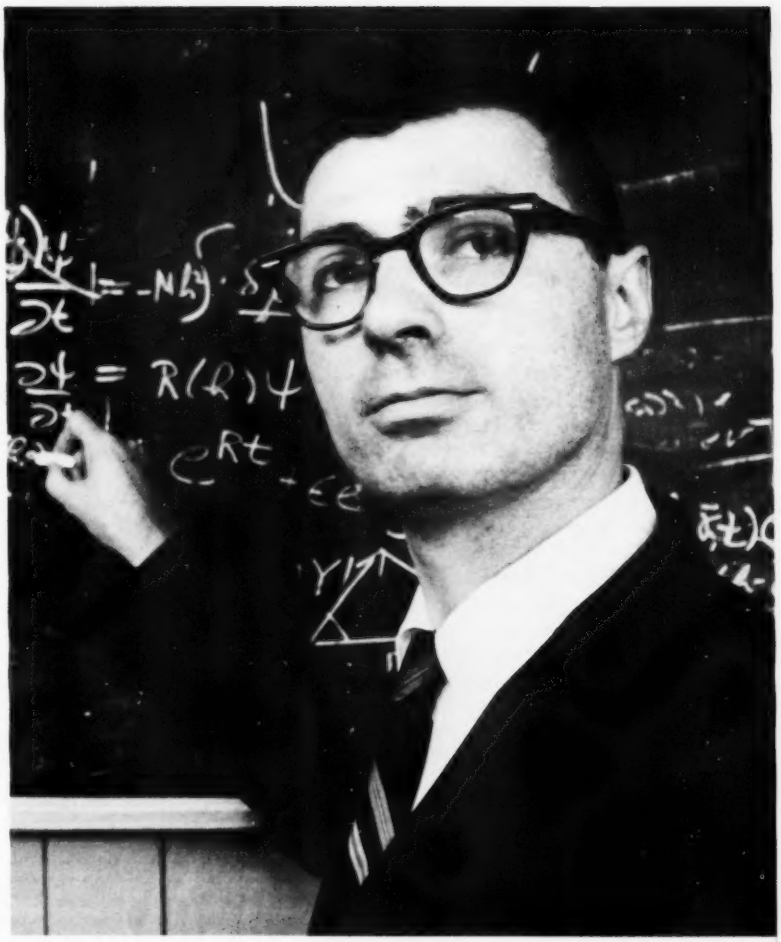
Dr. George F. Neilson, Jr., a Senior Scientist at the Owens-Illinois Technical Center, received his B. S. and M. S. degrees in Chemistry from Oregon State University, and his Ph. D. in Physical Chemistry from the Ohio State University in 1962. While at Oregon State, he was elected to Sigma Xi, Phi Lambda Upsilon, and Pi Mu Epsilon. He is currently a member of RESA, the American Chemical Society, the American Physical Society, and the American Crystallographic Association. Dr. Neilson has been a research scientist at Owens-Illinois since 1962, and is the principal investigator in the research summarized in this article.

The work of Dr. Neilson is part of a fundamental research program on the physics of the glassy state of matter sponsored by the Solid State Sciences Division, Directorate of Physical Sciences, AFOSR.



Dr. Neilson works at the blackboard on the theory of nucleation or separation processes in glasses.

economic modeling

DR. R. G. POHRER,
Directorate of
Mathematical Sciences, AFOSR

An economic model developed by Professors D. L. Hanson and C. F. Menezes of the University of Missouri, Columbia, under a grant from the Mathematics Division, AFOSR, has a number of interesting interpretations and extensions. Not the least of these is an extension to "individual bidding behavior in sealed tender buying markets," including investment decisions associated with the submission of proposals for the acquisition of research and development (R & D) contracts.

The authors describe the mechanics of one such kind of R & D contract market. It consists of a group of firms competing for a single contract to produce a specified quantity of a new product. The product is defined in terms of certain standards of performance and cannot be produced with existing technology. Each participating firm is required to submit a proposal on or before a given future date. The proposal consists of (1) a detailed statement of the production process the firm will use if awarded the contract, and (2) a bid price. The contract is awarded to the lowest bidder from among the proposals that meet the required standards of performance.

Initially, each firm must decide whether to begin the R & D work necessary for the submission of a proposal. R & D costs, production costs and the payoff are all unknown at this time. A first step toward a model explaining R & D proposal submission might be the extension of the model developed by Professors Hanson and Menezes (4) to the case where production costs are assumed to be random. As the authors explain, such a model would of course be useful in itself.

The basic economic model of Professors Hanson and Menezes can of course be interpreted and extended in directions other than the above. Specifically, certain interpretations in terms of war gaming, logistics and operations analysis are evident. The properties of the model can also be analyzed as they relate to the "hazard rate" or "failure rate" function in the mathematical theory of reliability.

With this introduction, it seems appropriate to describe the basic model, the statement and formulation of which comprise the substance of the authors' paper. As they state, the latter provides a theory of individual bidding behavior in competitive sealed tender markets. The objective is to formulate a bidding model in terms of modern utility theory and to derive its basic properties. The model presented differs in important ways from the expected utility maximization bidding models independently formulated by Greismer, Levitan, Shubik (3) and Smith (7). The latter assume that the bidder maximizes the expected utility of income. The present authors assume that the bidder maximizes the expected utility of wealth, an improvement in that utility is made to depend on both the size of the payoff and the level of initial wealth.

A second difference relates to the form of the utility function. The first three of the other authors implicitly assume that utility is a homogeneous linear function of income. It is well known that linear utility functions, homogeneous or not, imply "neutrality" to risk, i.e., that the individual will be indifferent to the choice between engaging in any arbitrary bet and receiving the sure option equal to the actuarial value of the bet. This type of implied behavior seems less than consistent with intuitive evidence and observation. On the other hand, Smith assumes in places that utility is quadratic in income. This form of utility function is very prevalent in the literature on decision-making under uncertainty, and has been the basis for the mean-variance approach to the theory of portfolio selection. As Arrow (2) has noted, it violates the principle of decreasing absolute risk aversion. It also implies that eventually wealth has negative marginal utility, so that it would be better to throw some away. Because of the implausible behavioral implication of both linear and quadratic utility functions, the authors assume that utility is a concave function of wealth, the most general form of utility function which characterizes risk-averse behavior.

Finally, the emphasis in this paper on deriving the formal properties of the model and giving this economic interpretation is also unique, and turns out to be rewarding. A natural relationship emerges between the principal properties of the model and certain tools and concepts which have been developed in some branches of mathematical statistics on the one hand, and in the theory of risk aversion on the other. Specifically, an investigation of the solution properties of the model reveals the important role of the "hazard rate" or "failure rate" function, a basic concept in the mathematical theory of reliability. At the same time, the authors find that some of the more important comparative statics properties of the model depend on the behavior or two functions, one of which has been independently established as a measure of risk aversion by Arrow (1, 2) and by Pratt (6). So far as is known, the other function has not been interpreted as a measure of risk aversion in the literature prior to the present paper. The authors establish it as such, and relate it to the work of Arrow and of Pratt.

The paper has been submitted to *Econometrica* for publication, and the interested reader may refer to that publication for further details.

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AFCRL backfire antenna developed for tactical satellite communications system

MICROWAVE PHYSICS
LABORATORY
AFCRL

The backfire antenna, a novel antenna first developed by Dr. Hermann Ehrenspeck of AFCRL in 1962, has been adopted by AFSC's Electronic Systems Division (ESD) for use as part of the Tactical Communications Satellite System. The TACSAT System, as the term implies, will use satellites to relay military tactical communications. The ground transmission and receiving equipment, of which the AFCRL antenna is a part, will be used by the Army and the Navy as well as by the Air Force.

Fifteen units of the UHF

Fifteen units of the AFCRL-developed backfire antenna have been built for AFSC's Electronic Systems Division by Collins Radio for use as part of the Tactical Communications Satellite (TACSAT) System. The AFCRL antenna was chosen for the system because of its relative simplicity and high performance characteristics. The antenna has a gain of 15 db. To obtain the same gain and approximately the same pattern quality, a Yagi antenna would have to be 11 times as long and have 27 dipole elements.

TACSAT ground terminals, in three different configurations, have been built by Collins Radio and are presently being service-tested. The ground equipments are designed for easy portability. The system operates at UHF and radiates up to one kw of power for transmitting and receiving both voice and teletype signals. The AFCRL antenna was chosen for the TACSAT System because of its relative simplicity and high performance characteristics. It has been designed (by the Collins Radio subcontractor, Radiation Systems, Inc.) to be opened and closed like an umbrella for easy transport, and has a diameter of about six feet.

The AFCRL backfire antenna, which led to the operational antenna, looks somewhat like a pie plate with a vertical rim. The bottom of the plate, which is the primary reflector, has a diameter of two wavelengths. The rim extends up a quarter wavelength. Located a half wavelength above the primary reflector is a smaller secondary reflector, and midway between these two reflectors (separated by a quarter wavelength from each) is a radiating dipole. This system acts like a partially open cavity, with the radiation reflecting back and forth between the two plates in a manner somewhat analogous to the way light energy reflects between the two mirrors in a laser cavity.

The gain of this antenna is 15 db. To obtain the same gain and approximately the same pattern quality, a Yagi would have to be 11 times as long and have 27 dipole elements, as compared with the simple feed dipole and the two plane reflectors of the backfire antenna.

The antenna can be designed in many configurations for different purposes. For example, a flush-mounted version for use as a receiving or transmitting antenna in missiles, satellites, aircraft and space vehicles has been demonstrated. It extends only about a half wavelength into the skin of the vehicle body, yet produces gains of more than 16 db with a single feed.

In addition to ESD's use of the backfire antenna in the Tactical Satellite Communications System, NASA is also considering this novel antenna principle for the construction of high-gain 136-MHz antennas for its world-wide tracking and telemetry network.

AIR FORCE SENDS RECORD-SIZE BALLOON TO RECORD ALTITUDE

AEROSPACE INSTRUMENTATION LABORATORY AFCRL

On 11 September 1968, AFCRL launched a 28.7-million-cubic-foot research balloon which reached an altitude of 158,000 feet. The launch established two balloon records: the balloon was the largest ever launched, and the altitude the highest ever reached by a research balloon.

The balloon was launched from the White Sands Missile Range in New Mexico. It was developed and launched for the Army Electronics Command's Atmospheric Sciences Office located at the missile range. The balloon carried a 425-pound payload–285 pounds of which was ballast–consisting of instruments for measuring atmospheric composition, pressure, temperature, density, ozone, and wind motion near the stratopause.

AFCRL launched the polyethylene balloon from a site near the center of the White Sands Missile Range. At the time of launch, the balloon was 587 feet long. At ceiling, because of the expansion of helium caused by decreased atmospheric pressure, the balloon assumed an onion-shaped configuration of about 352 feet by 410 feet. The balloon traveled in a westerly direction at about 10 miles per hour following its 6:58 a.m. (local time) launch. The flight was terminated near Needles, California, after 18 hours.

The flight represents a significant advance in balloon development. Polyethylene is the basic material used to construct research balloons, the conventional capacity of which is about 5 million cubic feet. Never before has a polyethylene balloon approached 28.7 million cubic feet in volume. The previous record size for polyethylene balloons–but not for balloons fabricated from other materials–was a 13.5-million-cubic-foot balloon launched by AFCRL in 1965. Five fiber-reinforced Mylar balloons having a volume of 26 million cubic feet (the previous record size) were flown by AFCRL for NASA in 1966 and 1967.

AFCRL's Arthur O. Korn, Jr. was the Flight Test Director for the launch.

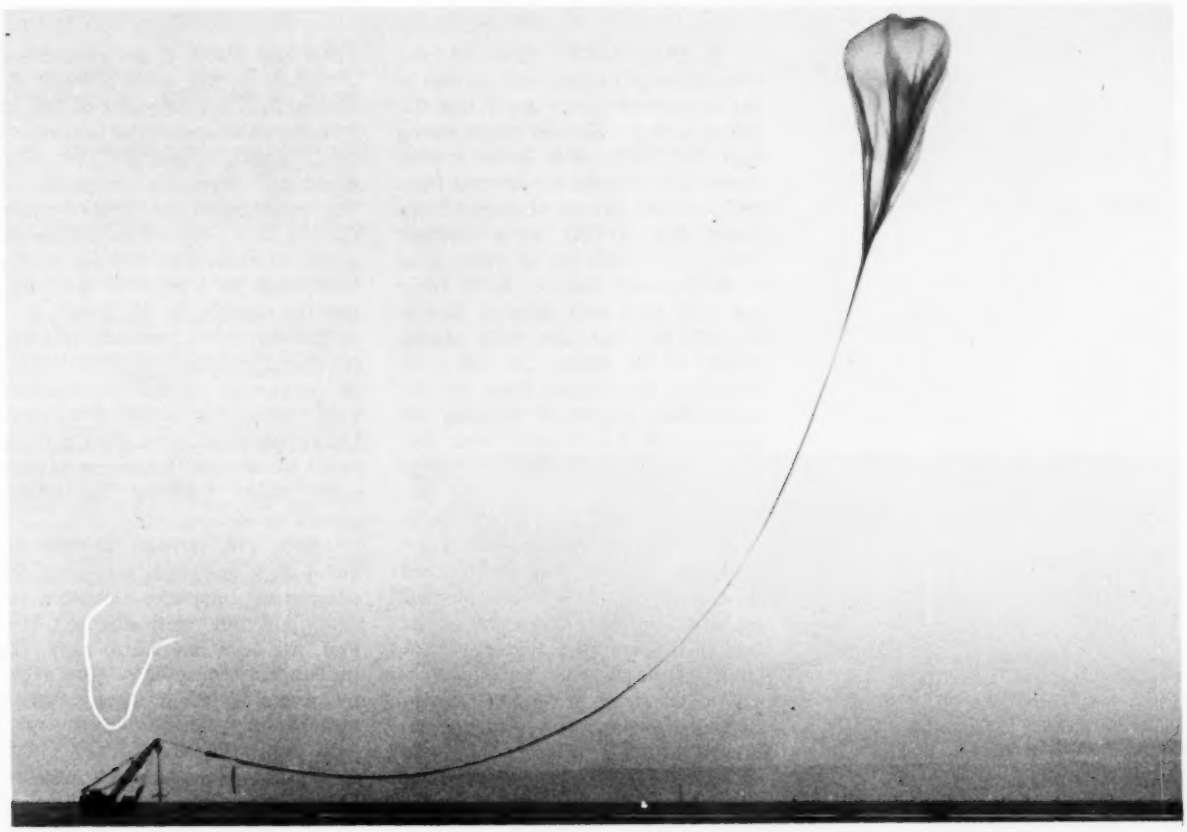


Figure 1. The 28.7-million-cubic-foot balloon just before launch.

Mr. Arthur O. Korn, Jr., is an aerospace engineer with the Balloon Research Branch of AFCRL's Aerospace Instrumentation Laboratory. He received his B.S. degree in Mechanical Engineering from the University of New Hampshire in 1957. From 1957 to 1958, he worked as a design engineer in the Advanced Car Division of the Ford Motor Company. And, from 1958 to 1960, he saw active duty with the USAF, serving as a project officer in the Balloon Systems Branch, Balloon Development Laboratory of what is now a portion of AFCRL.

After completing his military service, Mr. Korn accepted a position as research engineer with the Balloon Research Branch of AFCRL's predecessor organization's Research Instrumentation Laboratory. In his present capacity, he works on the design and development of polyethylene and reinforced balloons and associated ground and in-flight equipment and instrumentation. He is a member of the American Society of Mechanical Engineers and the Society of Automotive Engineers.

SOLID STATE SCIENCES
LABORATORY, AFCRL

growth of crystals by thermal imaging

In 1958, AFCRL "invented" the thermal image furnace, only to find in the subsequent patent search that the principle had a German origin dating back to 1927. After initial experiments with a model constructed from the parabolic mirrors of surplus Navy searchlights, AFCRL let a contract with A. D. Little for an operational crystal-growing furnace. A. D. Little not only built two different models for AFCRL, but also built several models of the furnace for sale commercially. For several years no one made much progress in realizing the potential of the furnace; other furnaces did the job just as well or better. So much for history.

It now appears, from work done at AFCRL by Dr. William G. Field and Robert W. Wagner, that the promised benefits of the thermal image furnace are about to be realized after all. The furnace is based on a simple but not too obvious optical phenomenon. Two parabolic mirrors are placed face to face, in a clamshell configuration. Now, if we cut small holes, about two inches or so in diameter, in the center of the mirrors and suspend an object outside one of the holes, a person viewing from the opposite side will see, apparently suspended in space, a fully-rounded 3-D image of the object. The viewer may be tempted to reach out and touch the image, only to be surprised when his hand passes through what he is convinced is a hard, physical object. This curious illusion led AFCRL to donate an early model of the parabolic mirror device to the Boston Museum of Science, where it has been on display for many years.

Now suppose we take two such facing clamshells (a dual system consisting of two pairs of searchlight mirrors) and place a heat source at the outside holes of each. If the spacing between the two clamshells is just right, the heat would be imaged through the inside holes of each pair at a common point. It is at this point that we place the necessary apparatus for growing crystals.

Using xenon arc lamps of high intensity (up to 20,000 watts) as heat sources, temperatures of between 1,500 and 3,000° C are produced at the focus in the space between the clamshells. The production of heat by focusing an image of the heat source offers several advantages, one being separation from the contamination that occurs when the crystal is grown directly in a flame as with Verneuil-grown crystals. The focusing of the heat image at a point in space also permits crystals to be grown in a completely sealed, optically transparent quartz chamber. Thus, crystals can be grown in special atmospheres, under pressure or in partial vacuums. Unlike induction heat sources, no magnetic or electric fields are present which might influence the crystal-growth process.

With this furnace, AFCRL has grown such crystals as manganese ferrite, spinel, sapphire, stabilized zirconia, and ruby. Most attention, however, has been devoted to ruby. The furnace has been used to grow rubies by several methods. One of these methods has yielded high-purity ruby, with low dislocation density ($1.0 \times 10^4/cm^2$) and a uniformity of chromium concentration across the crystal which varies by only about 1%. (Unevenness of chromium concentrations in the basic aluminum-oxide lattice structure that forms the ruby is a basic limitation of the Czochralski ruby-growing method.)

To obtain high-quality rubies, AFCRL simply regrows a Verneuil-grown ruby by a process similar to zone refining. The process starts with two rubies, a seed ruby of the desired orientation and a Verneuil feed ruby. The ends of the ruby rods are brought together until they almost touch. Heat is then applied to the two ends to create a melted zone between the two rods. The seed and feed rods are rotated in opposite directions to produce stirring action and to reduce temperature gradients. The seed and feed rods are slowly lowered through the heat zone, with the newly grown ruby boule being formed on the seed rod. By this process, AFCRL has grown high-quality ruby crystals a quarter inch in diameter and several inches in length.

Dr. William G. Field is a research physicist in the Purification & Growth Branch of AFCRL's Solid State Sciences Laboratory. He received his B.S. in Electronic Engineering from Kansas State College in 1943, his M.S. in Mathematical Physics from Northeastern University in 1953, and his Ph.D. in Geology from Harvard University in 1965. He served as an Army officer from 1943 to 1945 in aircraft warning and radar maintenance, and joined AFCRC, AFCRL's predecessor organization, in 1946.

In his present capacity, Dr. Field plans and conducts research in the field of extreme-temperature single-crystal growth of refractory materials, the correlation of such techniques with resulting crystal-perfection factors, and their ultimate performance in electromagnetic devices. The objective of this research is to develop specific knowledge about the use of controlled thermal energy in the crystallization process and to devise new analytical methods and techniques in the synthesis of new or improved materials. The research effort is devoted to growing single crystals by high-flux thermal imaging using double-clamshell optics.

Dr. Field is a member of the American Crystallographic Association, the Mineralogical Association of America, and Sigma Xi.

Mr. Robert W. Wagner is a research general physical scientist in the Purification & Growth Branch of AFCRL's Solid State Sciences Laboratory. He received a B.S. in Electrical Engineering from MIT in 1954. Before World War II, he was employed as a radio broadcast engineer with an affiliate of the Columbia Broadcasting System. He was called to active duty with the Navy in 1942 as a Lt. Jr. Grade, serving as instructor at the Naval Training School at MIT, and as electronics officer aboard an aircraft carrier. He returned to inactive status in 1946.

In his present capacity, Mr. Wagner does experimental research in the field of single-crystal growth techniques of highly refractory materials, the correlation of such techniques with resulting crystal structural factors, and their ultimate performance in devices such as the laser. This research is primarily concerned with developing experimental and analytical methods for the precise control of conditions during crystal growth, and for evaluating the results of such controlled growth in terms of importance to laser and related technology.

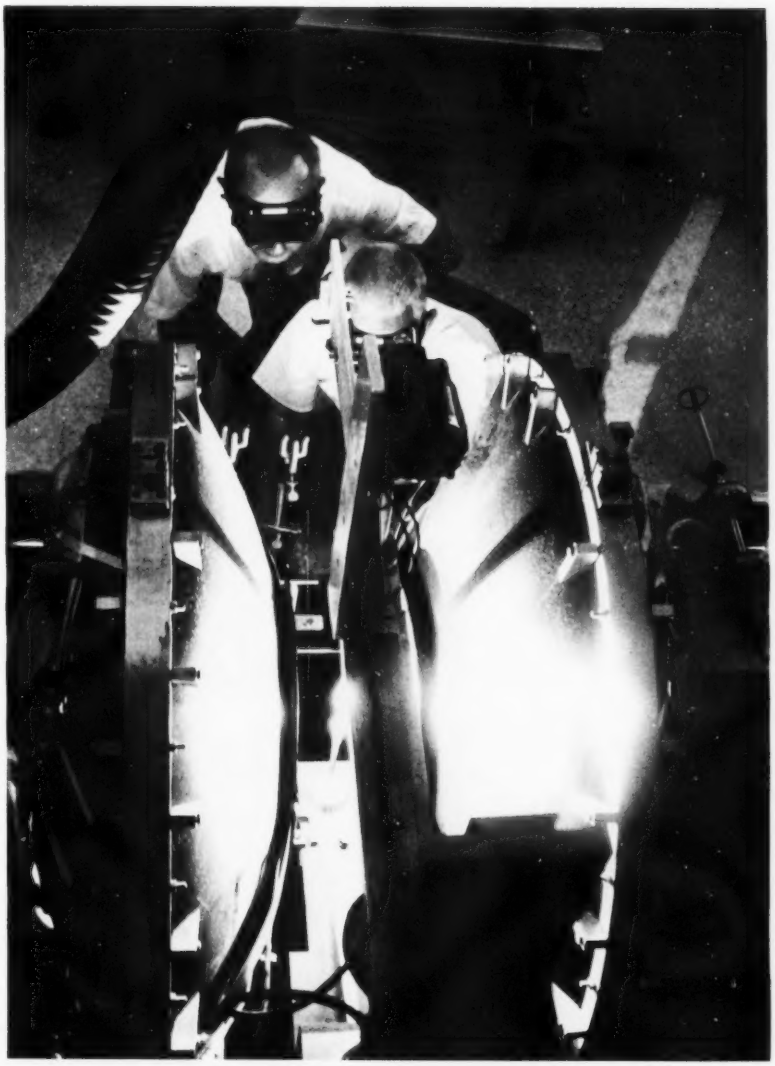


Figure 1. AFCRL arc image furnace. Dr. William G. Field is seen in the foreground, with Mr. Robert W. Wagner directly behind him.

THIN-FILM PIEZOELECTRIC TRANSDUCER

MICROWAVE PHYSICS LABORATORY, AFCRL

Under AFCRL contract, Westinghouse has developed a unique thin-film piezoelectric transducer for converting electricity to sound. The transducer has four times the power range and twice the frequency range of previous transducers.

The new transducer was made possible by the discovery of a method for depositing several thin layers of cadmium-sulfide material in such a way that the molecular orientation of each layer is reversed from the layer immediately above and below. A primary application of the thin-film cadmium-sulfide transducers is in acoustic delay lines, a basic component in radars and electromagnetic signal processing. The new delay lines could make possible the incorporation of delay lines on integrated circuit substrates. The transducers may have up to five alternating layers of cadmium sulfide, each about as thick as half the wavelength of the sound waves they handle. Total thickness is about 1 or 2 ten thousandths of an inch. The transducer is most effective when designed for a single frequency, but it can accommodate a broad band of frequencies if each layer has a slightly different thickness.

The reversal of the molecular orientation of the cadmium sulfide is accomplished by evaportating atop each layer a coating of lead sulfide only about 20 atoms thick. The lead sulfide causes the next layer of cadmium sulfide to grow with reversed orientation.

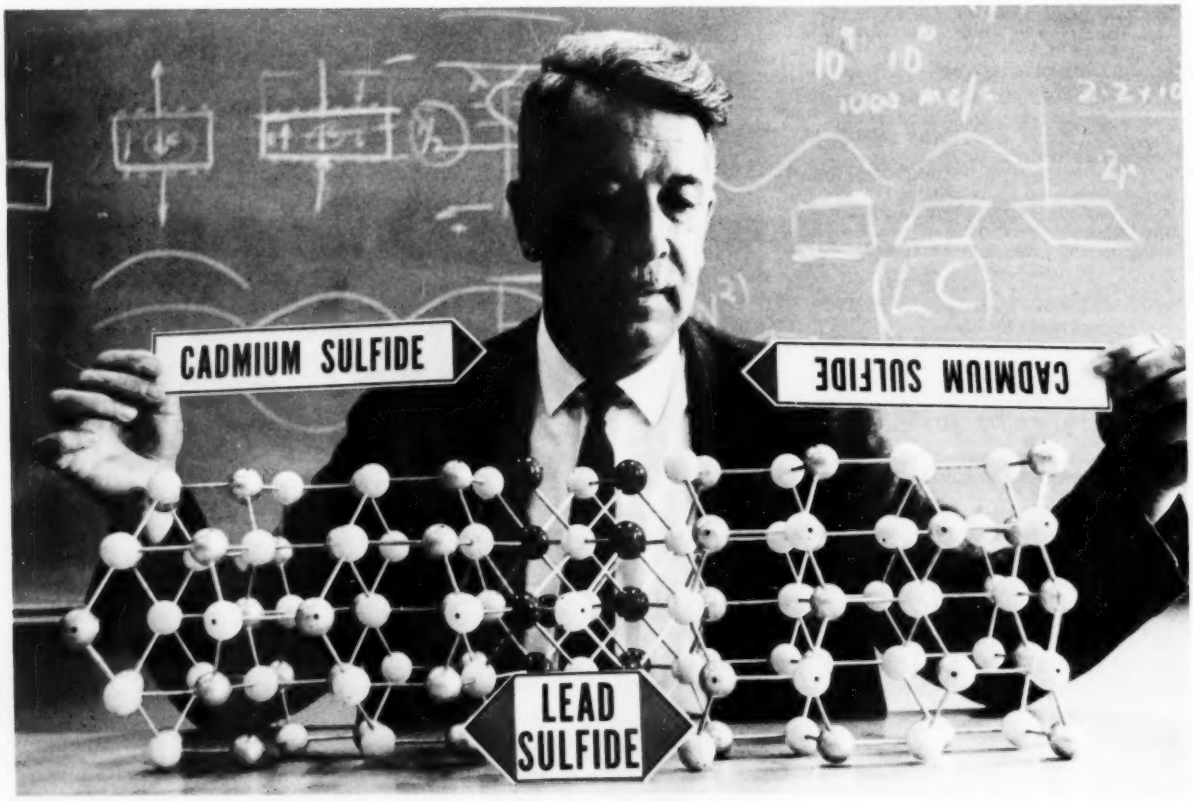


Figure 1. Upside-down sign indicates that either side of this molecular model is like the other side, but turned around. Dr. John de Klerk, a physicist at the Westinghouse Research Laboratories, demonstrates how to make actual molecular structures with flipped layers for use in electronic systems. He does it by including an extra-thin "filling" of special reversing material between layers. The model shows a section of a two-layer cadmium-sulfide structure with lead-sulfide filling. Molecular "layer cakes" of materials such as these will be used in specialized instruments to convert electric signals to sound waves with greater efficiency than previously possible. The research was supported by AFCRL.

space-forecasting system scheduled for completion by end of 1969

SPACE PHYSICS
LABORATORY, AFCRL

Quietly and with little advance notice, a large new Air Force system is being assembled that is scheduled for completion by the end of 1969. When fully operational, the system will predict geomagnetic disturbances, bursts of high-energy protons from the sun, increases or decreases in ionospheric density, the onset of auroral activity and, in general, any natural phenomena occurring on the sun and in space that may affect our manned or unmanned satellites or that may degrade the performance of ground-based military electronic systems used in communications, detection, surveillance, or navigation.

The system is being developed by AFCRL and the Air Weather Service (AWS) as part of the Space Forecasting Program. The heart of the system is the AWS UNIVAC 1108 computer complex at Offutt AFB in Omaha, Nebraska. Linked to this computer is a worldwide communications net providing real-time data inputs from more than 50 observing stations.

The computer complex and most of the stations have been in place for some time, routinely providing data for the AWS Solar Forecasting Center in Colorado Springs. Because the system requires little new hardware development, it has not followed the usual systems development route. Development efforts have focused on techniques and software programs for uniting the loose network of observing stations into one system.

The most scientifically significant feature of the system is that it draws upon the observations of most of the environmental sciences. Atmospheric and geomagnetic phenomena, usually fragmented into diverse and isolated fields of study, will be studied as a unified whole and continuously processed and correlated to define with greater precision the interactions and cause-and-effect relationships among observed phenomena. AFCRL is a major center for research in the environmental sciences. The system draws heavily upon AFCRL's research and specialized scientific skills. The Space Forecasting Program was started in 1964 and is under the direction of Dr. Fred Ward.

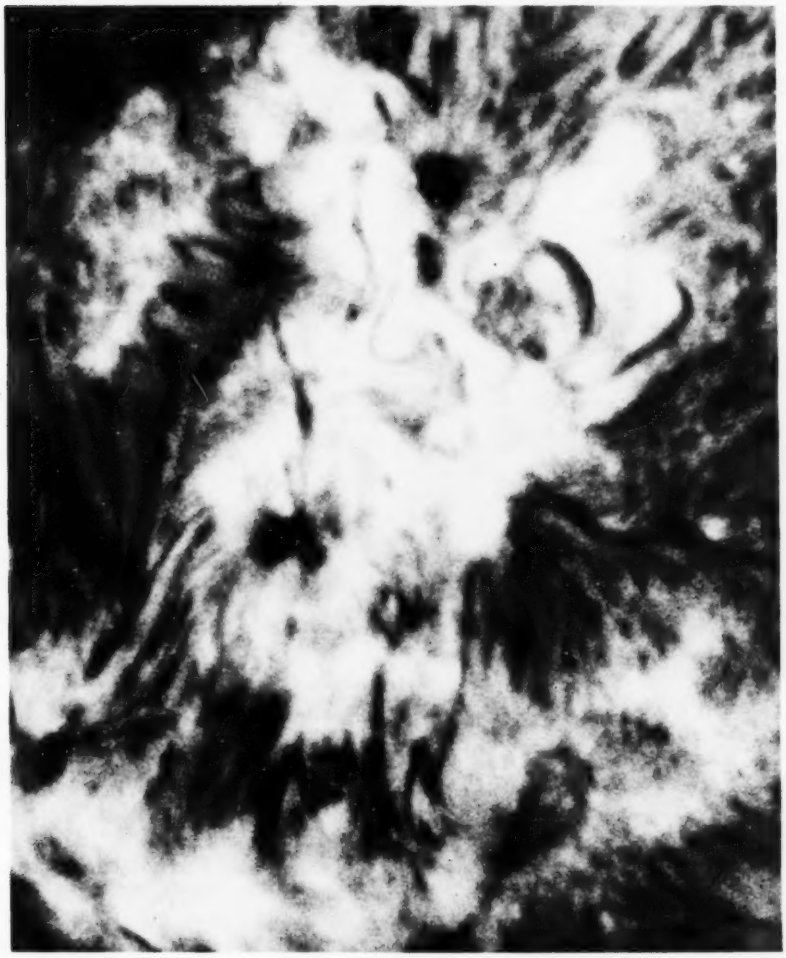


Figure 1. Solar active center. Clearly visible are two sunspots and the various surrounding striations caused by solar magnetic fields. Through the study of sunspots and the associated structure, solar physicists hope to predict the occurrence of solar flares and prominences.

The Sun and Terrestrial Effects: The Space Forecasting System revolves about the sun. Of the many sensors and observational instruments that supply system input data, those that look at the sun are fundamental. The essential first step to space forecasting is an understanding of the patterns of change that we observe on the sun.

The sun emits electromagnetic energy across the whole spectrum from long wavelengths, through the infrared and optical portions of the spectrum and beyond into the ultra-

violet and X-ray regions. And it emits a continuous flux of particles of varying energies. Both particle and wave emissions have pronounced effects on the earth's environment.

What are these effects? Primarily, they create geomagnetic disturbances and alter the density of the earth's ionosphere. When this happens, electronic communications and navigation systems are affected worldwide. The performance of our surveillance radars in the northern latitudes is degraded and, under certain conditions, many false targets appear. Sometimes, after explosive bursts of high-energy protons from the sun, there is a complete radio blackout in the polar regions. Associated with radio disturbances are enhanced auroral activity and changes in airglow levels. Both aurora and airglow, insofar as delicate optical surveillance instrumentation aboard satellites is concerned, represent so much noise obscuring the view.

Establishing Prediction Criteria: The Space Forecasting System, when operational, will help the AWS to forecast, days or weeks in advance, when solar-induced effects on the terrestrial environment will occur. To make these predictions, one looks for prediction clues, tries to find out what correlates with what, and looks for all possible precursors to the events. A major AFCRL task is to establish prediction criteria.

If we can predict changes in solar-energy emissions, then one day we may be able to correlate these with the variations in the chemistry, physical properties, and dynamics of the upper air, and thus also predict these environmental variations. All are modulated by the sun.

Establishing prediction criteria requires that we examine tens of thousands of measurements of sunspot characteristics–size, number, magnetic complexity–for each solar active region. These must be related to other visible features such as plages, coronal emissions, and filament patterns. Then both must be evaluated against the intensity and characteristics of radio emissions at a number of wavelengths and their location on the sun. There are many other observables–some which may not now appear important–that must go into the final equation. Prediction criteria, it is expected, will be continuously refined over a period of many years, based on the experience gained from operation of the Space Forecasting System.

Figure 2. AFCRL's 28-ft telescope at Hamilton, Mass., used in AFCRL's solar-flare prediction program. The telescope monitors the sun continuously throughout the day.

Dimensions of the Forecasting System: The initial system network has been established.

Optical solar data will be received from 12 solar observatories. One of the most important is the AFCRL Sacramento Peak Observatory in New Mexico. Others are located at Los Angeles, Hawaii, Manila, Athens, Tehran, Puerto Rico, Boulder, the Canary Islands, NASA/ESSA sites in Houston, and two Australian sites, Culgoora and Carnarvon.

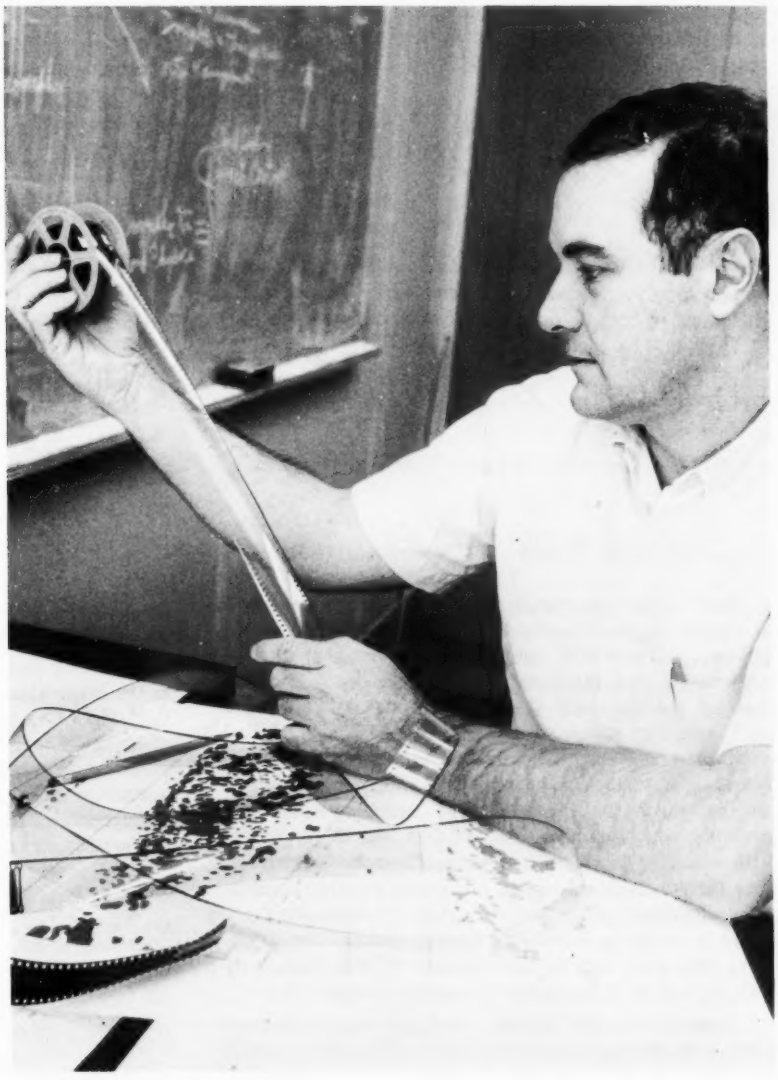
Radio data at different frequencies will be received from radio telescopes at AFCRL in Massachusetts,

Stanford, Manila, Ottawa, Athens, Los Angeles, and Boulder. Geomagnetic data will be received from magnetometer sites at Thule, Greenland; Loring AFB, Maine; Eielson AFB, Alaska; and Melville, Canada.

Particle flux intensity and solar X-radiation data will be observed by the Vela satellites whose instruments, although designed to detect nuclear explosions in space, are particularly well suited for monitoring solar emissions. The ionosphere will be monitored for density changes by riometers located at more than 36 stations covering the entire globe.

Data from these collectors will be transmitted directly to the Offutt AFB UNIVAC 1108 computers in a standardized format and code, and in real-time.

Scientific Fallout: The Space Forecasting System evolved from knowledge uncovered by astronomy and the environmental sciences–the normal progression in which science precedes technology. But, through the operation of the system, the environmental sciences will realize benefits in return. The standardization of solar and upper-atmosphere data, and the techniques for correlating the data on a real-time, long-term, continuous basis, all promise to enhance our understanding of solar processes and the effects of these processes on the terrestrial environment. From the scientific standpoint, the system may prove in the long run to be more valuable than the huge international programs of scientific observations carried out during the International Geophysical Year in the 1950's, as well as the International Quiet Sun Year more recently completed.



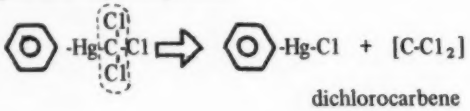
Dr. Fred W. Ward is a physicist with the Space Forecasting Branch, Space Physics Laboratory, AFCRL. He attended the Massachusetts Institute of Technology from which he received the degree of Bachelor of Science in Meteorology in 1952. In 1955 he received his M.S. degree, and in 1957 his dissertation, "Power Spectra of Astrogeophysical and Meteorological Time Series," won him a Ph.D. degree.

Except for a short term of active duty in the Air Force in 1953, Dr. Ward has worked continuously for AFCRL and its predecessor organizations since 1952. He masterminded the Weather System 433L from 1957 through 1958. And, from 1958 to 1963, he was with the Dynamics Branch of the Meteorology Laboratory working on a number of astrogeophysical problems. Since 1963 he has worked in the Space Forecasting Branch on space environmental forecasting and the general circulation of the solar atmosphere. Dr. Ward has several publications to his credit.

REACTIVE CARBENE INTERMEDIATES

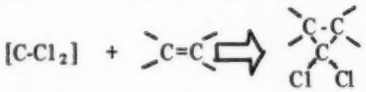
DR. ANTHONY J. MATUSZKO, Directorate of Chemical Sciences, AFOSR

Chemists concerned with the synthesis of new materials have made use of a variety of highly reactive chemical species. These reactive species are often generated *in situ*, and usually contain an element in an unstable low-valency state. They occur as intermediates with short lifetimes, requiring low activation energies for reaction. Divalent carbon intermediates, commonly referred to as methylene derivatives or carbenes, are highly reactive substances of this type. With support from the AFOSR Directorate of Chemical Sciences, Dr. Dietmar Seyferth at the Massachusetts Institute of Technology has been investigating new ways of generating various carbenes in solution by way of elimination reactions from organometallic precursors. Typical of reactions studied by Dr. Seyferth and his research group is the following "extrusion" of a dihalocarbene from an organomercury compound.

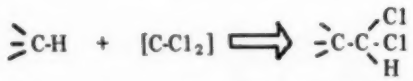


dichlorocarbene intermediate

The carbene may then react across a double bond to form a *gem*-dichlorocyclopropane (the *gem*-dichlor- refers to the attachment of both chlorines to the same carbon atom),

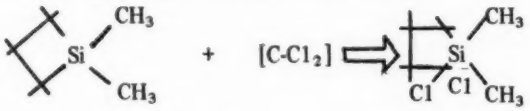


or it may take part in one of many "insertion" reactions.



Such reagent systems are of great value since they allow the generation and transfer to a substrate of a substituted carbene under very mild conditions in the virtual absence of complicating side reactions. This has allowed a study in detail of the chemistry of carbenes, and has allowed the M.I.T. scientists to carry out carbene reactions which had never been observed before because alternate carbene-generating systems were incompatible with product formation or existence. Organomercury systems have been developed which transfer CCl_2, CClF, CBr_2, CClBr, CHCl, CHBr and CH_2 to various organic and inorganic substrates. Since the reactions are carried out *in situ* without isolation of intermediates, the actual formation of carbenes is not always a certainty. However, kinetic studies have established that CCl_2 was an intermediate in the reaction of C_6H_5-Hg-CCl_2Br with olefins in benzene solution (1).

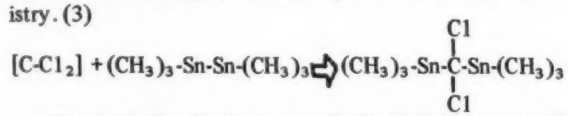
Recently, the M.I.T. research team reported a new reaction which was noteworthy for two reasons: it represented the first reported CCl_2 insertion into a silicon-carbon bond as well as the first insertion of CCl_2 (with ring expansion) into a strained cyclic system. (2)



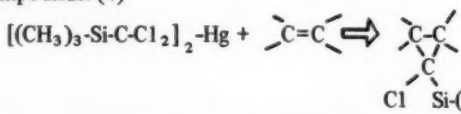
4-membered carbon-silicon ring

5-membered carbon-silicon ring

The study of compounds containing covalent metal-to-metal bonds has received much attention in the past few years. The discovery of the first case of dihalocarbene insertion into a metal-to-metal bond to give a stable -M-CX_2-M- system has opened up a broad new field of research in the organometallic aspects of carbene chemistry. (3)



Recently, Dr. Seyferth and E. M. Hanson, a graduate student at M.I.T., reported the preparation and reactions of the first functional carbene reagent, an organomercury compound which transfers $(CH_3)_3SiCCl$ to olefins and Si-H compounds. (4)



This compound may now be added to the arsenal of useful reagents in synthetic organosilicon chemistry.

These are only a few of the many new developments in the chemistry of reactive carbene intermediates coming out of Dr. Seyferth's laboratory. The C_6H_5-Hg-CX_3 reagents, whose chemistry was developed with AFOSR support, have been finding increasing use in organic synthesis, particularly in the preparation of cyclopropanes. One of these reagents, $C_6H_5HgCCl_3$, has found its way into the Eastman Catalog of chemical reagents commercially available for laboratory use. During his travels Dr. Seyferth has noted industrial interest in these mercury reagents which may be useful for adding dihalocarbenes to carbon-carbon double bonds in polymers from 1,3-dienes.

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(3) Communication *Journal of the American Chemical Society, 89,* 2790, 1967. (Full paper accepted for publication in *JACS,* and will appear in early 1969.)
(4) Communication *Journal of the American Chemical Society, 90,* 2438, 1968.

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